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ESR bottleneck effect in the heavy-fermion metal $YbRh_2Si_2$

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Abstract

An approach related to the bottleneck effect is proposed for an origin of the electron spin resonance (ESR) of a Kondo ion (Yb^{3+}) in the undoped Kondo-lattice systems $YbRh_2Si_2$ and $YbIr_2Si_2$. The effects observed for the effective ESR g-factor and the ESR linewidth in $YbRh_2Si_2$ are associated with the influence of the Kondo effect and the crystalline electric field splitting of the f-multiplet of ytterbium. A corresponding theory, which predicts the exchange-narrowed ESR linewidths in the temperature range 1–10 K, is discussed.

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Keywords: Quantum criticality; Heavy-fermion; Yb-compound; Kondo effect; Electron spin resonance and relaxation

1. Introduction

The magnetic and transport of ternary intermetallic RT_2X_2 compounds (RE = rare earth, T = transition metal and X = Group IV or Group V element) are determined by the rare-earth moments, their conduction electron (CE)-mediated exchange interaction, and the effects of the crystalline electric field (CEF) acting on the 4f electrons. The method of electron spin resonance (ESR) can yield important information on the electronic structure, on the interaction between the magnetic rare-earth spins and the CE, and on the spin correlations in the lattice.

$YbRh_2Si_2$ is one of a few ytterbium-based heavy-fermion (HF) Kondo-metals exhibiting the properties of a so-called non-Fermi-liquid behavior (NFL) very close to a quantum critical point (QCP), where magnetic ordering via RKKY interactions is balanced by Kondo screening (see Ref. [1] and references therein). Anomalous behavior of the resistivity, specific heat and magnetic properties investigated in this compound suggests a fundamental breakdown of the Fermi liquid theory. Most remarkably, in contrast to the Ce-based NFL superconductors, $YbRh_2Si_2$ is not a superconductor at least at the lowest accessible temperature $T = 10\,\mathrm{mK}$. Unraveling the intimate relationship between quantum criticality and superconductivity will remain a key issue in the physics of condensed matter [2].

2. Experimental results and discussion

An effective Kondo temperature of order 20–30 K was derived from different transport and magnetic measurements in $YbRh_2Si_2$ [1,2]. In the framework of known theories of the ESR for Kondo systems, such a Kondo temperature should be related to the ESR linewidth of 25–40 T [3]. An estimation of the dipole–dipole ESR linewidth only, caused by spin–spin interactions, yields in $YbRh_2Si_2$ the value of order 0.16 T [4]. Thus, the Kondo ion itself as a part of ground lattice is not an appropriate ESR probe, and it is necessary to dope HF systems with small amounts of ions with stable magnetic moments in order to observe any measurable ESR signal. Since the structure of the RET_2X_2 compounds is complicated, it is very difficult to obtain the information about magnetic exchange interactions from theoretical calculations. In addition, the character of the ground state in the HF compounds is often governed by several different microscopic interactions of comparable strength (Kondo effect, interatomic magnetic interactions and CEF). Therefore, such kind of doping induces different disorder effects, which also could substantially hinder a further evaluation of experimental ESR data. However, for the first time, a

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